THE MEDICAL BULLETIN OF
SISLI ETFAL HOSPITAL

DOI: 10.14744/SEMB.2025.04206
Med Bull Sisli Etfal Hosp 2026;60(1):1-8

Review

The Role of Bedside Ultrasonography in Neonatal Central Venous Access Applications

Adil Umut Zubarioglu, Ali Bulbul, Hasan Sinan Uslu

Department of Neonatology, Şişli Hamidiye Etfal Training and Research Hospital, İstanbul, Türkiye

Abstract

Vascular access in critically ill neonates is crucial for management and is often challenging. Neonatal venous access must allow for the administration of all necessary medications and diagnostic tests. For these purposes, the catheter must be centrally located. Therefore, determining the correct location of the tip of central venous access devices is crucial, and traditionally, this assessment has relied on thoracoabdominal radiography. However, this method has limitations; it is an indirect method that uses radiological landmarks, is postprocedural, can only be used for tip location, and has long-term risks because of ionizing radiation. Current guidelines recommend that the imaging method used in central venous access procedures be real-time, intraprocedural, rapid, accurate, easy to use, noninvasive, reproducible, and inexpensive. Bedside ultrasonography, which possesses all these features, is considered the ideal imaging method. Ultrasonography is used with various catheter types for selecting the appropriate vein for catheterization, during needle insertion, for advancing the catheter in the correct direction, for catheter tip navigation, for determining catheter tip position, for monitoring puncture-site-related complications, and for identifying and monitoring late complications. The goal of this review was to examine the advantages and feasibility of using bedside ultrasonography in central venous catheter insertion procedures, especially in the newborn period.

Keywords: Central venous access, central venous catheter, newborn, ultrasound

Please cite this article as "Zubarioglu AU, Bulbul A, Uslu HS. The Role of Bedside Ultrasonography in Neonatal Central Venous Access Applications. Med Bull Sisli Etfal Hosp 2026;60(1):1-8".

The two most important aspects of managing critically ill newborns are ensuring a secure airway and establishing venous access. Venous access is essential for all sick newborns, making it especially crucial. Neonatal venous access must allow for the administration of all necessary medications and diagnostic tests. For these purposes, the catheter must be centrally located. According to the latest WoCoVA (World Congress on Vascular Access, Prague 2024) classification, a catheter is considered a central venous catheter (CVC) only if the catheter tip is at the cavoatrial junction. A catheter tip positioned more proximally is considered peripheral and does not permit the administration of all required treatments. A catheter tip positioned further into the right atrium increases the risk of intracardiac complications. Therefore, determining the correct location of the tip of central venous access devices is crucial, and traditionally, this assessment has relied on thoracoabdominal radiography.

However, this method has limitations. First, X-ray is an indirect method and is flawed because tip location is determined by radiological landmarks (vertebral body, diaphragm, and heart silhouette).[1,2] Additionally, X-ray is a

Address for correspondence: Adil Umut Zubarioglu, PhD. Department of Neonatology, Şişli Hamidiye Etfal Training and Research Hospital, Istanbul, Türkiye
Phone: +90 505 787 75 33 **E-mail:** uzubari@hotmail.com

Submitted Date: October 22, 2025 **Revised Date:** November 11, 2025 **Accepted Date:** November 20, 2025 **Available Online Date:** March 23, 2026

postprocedural method and can only be used for tip location, not for tip navigation. Because it is performed after the procedure, delays may occur, and tip repositioning may be necessary. This exposes the newborn to additional ionizing radiation, which is associated with long-term harm.[3,4]

Current guidelines recommend that the imaging method used in central venous access procedures be real-time, intraprocedural, rapid, accurate, easy to use, noninvasive, reproducible, and inexpensive.[5] Bedside ultrasonography, which possesses all these features, is considered the ideal imaging method. The use of bedside ultrasonographic imaging at various stages of central venous access procedures is recommended in current guidelines, and its frequency of use is increasing worldwide. Ultrasonography is used with various catheter types for selecting the appropriate vein for catheterization, during needle insertion, advancing the catheter in the correct direction, catheter tip navigation, determining catheter tip position, monitoring puncture-site-related complications, and identifying and monitoring late complications.[6,7]

At the eighth WoCoVA held in 2024, four types of central venous catheters were defined for use in the neonatal period:

1. Umbilical Venous Catheter (UVC)
2. Peripherally Inserted Central Catheter (PICC) – Epicutaneo-Caval Catheter (ECC)
3. Centrally Inserted Central Catheter (CICC)
4. Femorally Inserted Central Catheter (FICC)

All medications and solutions can be administered through these catheters. Blood products can be administered through UVC, CICC, and FICC, and blood samples can be collected for laboratory analysis. Hemodynamic monitoring can be performed depending on the tip location, particularly if the tip is in the right atrium.

Currently, the use of ultrasound guidance is considered mandatory for CICC and FICC placement, and it is recommended for UVC and PICC placement.

In this review, we present current literature data on the use of bedside real-time ultrasound in various central venous access device (CVAD) applications in neonates.

The Role of Bedside Ultrasonography in Umbilical Venous Catheter Placement

The Umbilical Venous Catheter (UVC) is the most commonly used central venous access device (CVAD) in neonates, accessing the inferior vena cava (IVC) through the ductus venosus via the umbilical vein. Because the umbilical vein is rapidly accessible with direct visual inspection and catheter placement is relatively easy, the UVC can be used in neonates of all gestational ages. It permits administration of all necessary medications and blood product transfusions for the management of critically ill neonates and enables sample collection for laboratory studies.[8]

For the catheter to be considered central, the tip should be positioned at the junction of the right atrium and the inferior vena cava.[9,10] This position is considered safe and is associated with minimal complications.[11–13] Traditionally, the depth to which the catheter is advanced is determined by various formulas.[14,15] Catheter tip navigation is performed blindly into the venous system, and anteroposterior chest radiography remains the most commonly used radiological method for determining tip location after the procedure, with the vertebral body and cardiac silhouette serving as radiological landmarks.[16] However, in recent years, numerous studies have demonstrated the accuracy and effectiveness of catheter navigation and tip location determination using ultrasound, and real-time ultrasound has become the gold standard.[17–23]

It is fast, accurate, safe, and inexpensive compared with other methods. It can also be repeated as often as desired at the bedside and is valuable for early detection of catheter migration, which can lead to late-term complications. In the literature, success rates using ultrasound for tip location determination range from 95% to 100%.[24] The probe types used in the studies are linear (5–12MHz), linear hockey stick, micro-convex (7–8.5MHz), and small sectoral probes.[17,19,20,25,26] (Fig. 1).

While the subcostal longitudinal view is the most commonly used acoustic window, some studies have used the apical four-chamber and parasternal short-axis views.[25,26] (Fig. 2).

Some studies use a saline flush as an adjunct to enhance visualization of the tip location.[19,25] Furthermore, various studies have shown that the catheter can be advanced to a central placement by aligning the umbilical vein, ductus venosus, and IVC with constant pressure from the probe and navigating the catheter tip during the procedure.[26,27]

The need for ultrasound (US) training, along with the constant availability of trained personnel and necessary equipment, is seen as a disadvantage that reduces sustainability. Because most neonatologists still consider US training lengthy and difficult, chest radiographs remain the preferred method for determining tip location. However, studies have reported that providing short-term basic US training to nurses and physicians increases the use of ultrasound and improves the accuracy of tip location determination.[18,28,29]

If resistance is felt approximately 1–3cm before the estimated insertion depth for UVC, the catheter tip is likely stuck at the bifurcation of the right and left portal veins. This often occurs when insertion is performed blindly, and the best

Figure 1. Probe types used in neonatal vascular access applications. 1. Small sectoral probe, 2. Microconvex probe, 3. Linear probe, 4. Linear hockey stick probe.

way to avoid this problem is to use ultrasound-guided tip navigation. By placing a small 7–8MHz sectorial probe in the epigastric region, between the umbilical cord and the xiphoid, it is possible to gradually follow the catheter's progress within the liver until it reaches the junction between the IVC and the right atrium. If necessary, applying gentle pressure with the probe can help guide the catheter to its target, preventing misdirection within the liver.[26]

One of the noninfectious complications of UVC is post-insertion migration. This complication has been reported in 50% to 90% of cases in various studies.[24] It usually occurs due to shortening of the umbilical cord as it dries. In a prospective cohort study, the direction and magnitude of catheter tip migration were measured. An inward migration pattern is observed in the first 48hours after catheter placement, but migration subsequently becomes outward. Inward migration is due to negative pressure from increased lung volume, while outward migration occurs secondary to increased intra-abdominal pressure from intestinal gas.[23] The risk of catheter tip migration is a strong reason to monitor tip position using ultrasound.

The Role of Ultrasonography in Peripherally Inserted Central Catheter (PICC) Applications

A PICC is a catheter inserted through a superficial peripheral vein and advanced to a central location. In current publications and guidelines, it is also called an epicutaneo-caval catheter (ECC).[30] It is particularly essential for the care of very small premature infants and is an ideal tool for protecting peripheral veins while administering total parenteral nutrition and medications not recommended for peripheral veins. However, it is not suitable for blood sampling or transfusion because of its small internal diameter (1–2.7Fr) and low flow rate.

Ideally, the tip should be positioned at the junction of the superior vena cava and right atrium (SVC/RA) when inserted from the upper extremity or scalp/neck veins, or at the junction of the inferior vena cava and right atrium (IVC/RA) when inserted from the lower extremity, to expand the infusate range and reduce the complication rate. Traditionally, indirect measurements are made before the procedure to advance the catheter to this location, and after reaching the measured distance using a blind technique, the tip location is determined by plain radiography.[31]

A PICC tip placed in the upper extremity or scalp should be radiologically positioned at the level of the fourth thoracic vertebra (T4), which corresponds to the SVC/RA junction. Conversely, a PICC tip placed in the lower extremity should be radiologically positioned at the level of the body of the ninth thoracic vertebra (T9), which corresponds approximately to the IVC/RA junction.[26,30] These positions carry a low risk of PICC-associated complications.[32]

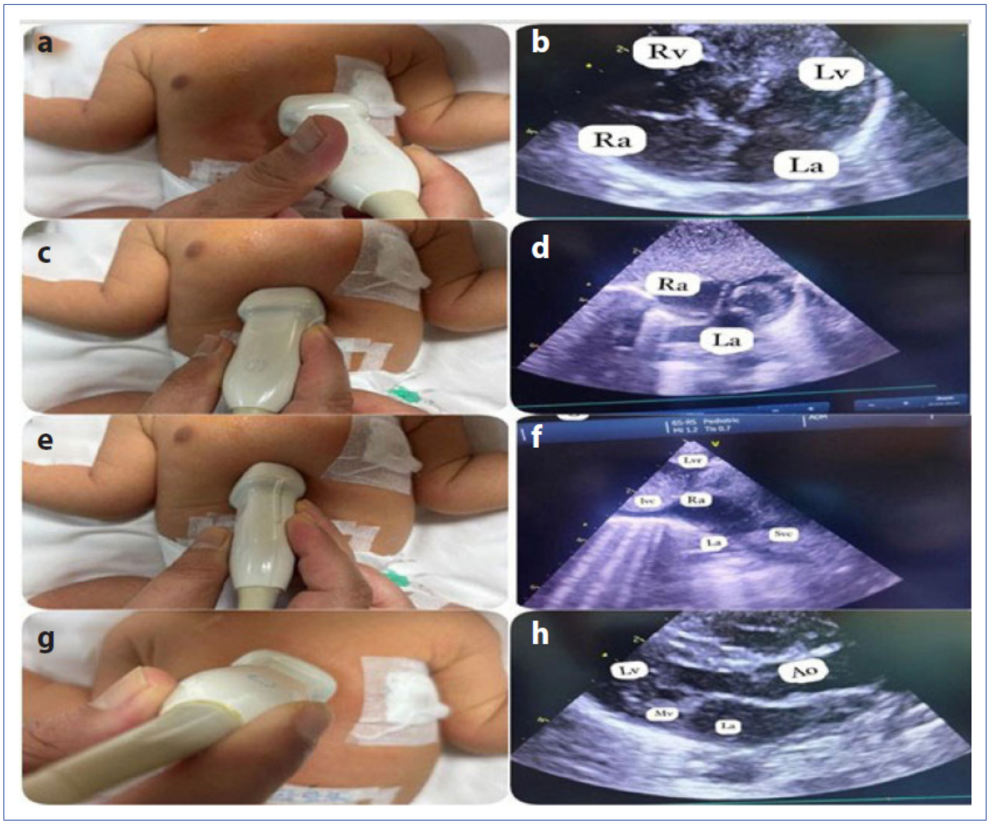

Figure 2. Acoustic windows and probe positions. **a.** Apical four chamber probe position, **b.** Four chamber view. **c.** Subcostal longitudinal probe position, **d.** Subcostal longitudinal view. **e.** Parasternal short axis (bicaval) probe position, **f.** Parasternal short axis (bicaval) view. **g.** Parasternal long axis probe position, **h.** Parasternal long axis view. (Rv: right ventricle, Lv: left ventricle, Ra: right atrium, La:left atrium, Lvr:liver, Ivc: inferior vena cava, Svc: superior vena cava, Mv: mitral valve, Ao: aorta).

However, this method has several disadvantages. First, the SVC/RA and IVC/RA junctions are not directly visible on X-ray but can be seen indirectly. Because the X-ray is taken after the procedure, the catheter must be repositioned if it is in an undesired position. This is unsafe due to X-ray exposure. Furthermore, because the catheters are very thin, they are difficult to visualize on X-ray, and additional contrast material may be required, making another X-ray necessary.

In recent years, the use of ultrasound for PICC tip location determination has been evaluated in many clinical studies.[26,33–35] Real-time ultrasound for tip location determination is noninvasive, rapid, and intraprocedural, reducing the need for repositioning.[34,36,37] It is also safe because it does not require radiation or additional contrast agent administration. Since the rate of secondary malposition due to migration is 30–35% with PICC use, intermittent ultrasound can also be used to monitor tip position.[38] Secondary malposition is associated with pleural and cardiac effusion, cardiac tamponade, endocarditis, extravasation, and deep vein thrombosis and can be diagnosed with appropriate ultrasound follow-up.

Linear probes or small sectorial probes have been used for tip location determination.[26,36] Different acoustic windows, such as apical four-chamber, parasternal long-axis, short-axis, and subcostal longitudinal (bicaval), have been used, and a saline flush is used to provide better imaging.

For PICC tip navigation, the Neo-ECHOTIP protocol describes how real-time ultrasound can be performed using a linear hockey stick probe (10–14MHz) according to the insertion site.[26]

Although studies have shown that ultrasound-guided PICC tip localization is effective and safe, most neonatologists still prioritize chest radiography. This may be because ultrasound training requires more advanced training (such as targeted echocardiography, Rapid Central Vein Assessment (RaCeVA), Rapid Femoral Vein Assessment (RaFeVA)) than training for UVC. Information on how this training should be conducted is limited, but clinical studies have shown that the rate of successful tip visualization is directly proportional to the clinician's experience level.[26]

The Role of Ultrasonography in Centrally / Femorally Inserted Central Catheter Applications

Central venous catheterization can be performed by percutaneous cannulation of superficial, palpable veins or by percutaneous cannulation of deep veins using various techniques, such as the blind technique, anatomical landmarks, or ultrasound guidance.[39] In the past, percutaneous venous puncture guided by anatomic landmarks was the primary method for central catheter insertion. However, even in the hands of experienced operators, this blind approach is associated with complications (such as accidental arterial puncture, pneumothorax, and hemothorax) reported in 60–95% of cases. The incidence of mechanical complications increases up to sixfold, especially after more than three attempts at venipuncture.[40] Direct radiography is recommended after these procedures. These methods are less accurate, unreliable due to the use of X-rays, expensive, and may require repositioning and additional anesthesia and sedation for post-procedure evaluation. Because of these drawbacks, these methods have begun to be abandoned.[41]

Ultrasound-guided central venous catheterization, recently introduced into neonatology practice, is safe and practical in experienced hands and has gained recognition in consensus statements and guidelines.[42–54] It is safe even in very small preterm infants, and high-performance catheters can be placed with high success rates and minimal risk of complications.[42–46] The brachiocephalic vein, internal jugular vein, subclavian vein, and common femoral vein are commonly used. Ultrasound is employed not only during insertion but also to measure vein diameter and to determine the most appropriate vein for the catheter size before the procedure.[55]

The use of the RaCeVA (Rapid Central Veins Assessment) and RaFeVA (Rapid Femoral Vein Assessment) protocols is recommended by the GAVeCeLT (Italian Group for Venous Access Devices) for pre-procedural assessment of vein diameters, lumen patency, and the relationship with surrounding tissue.[56,57] These assessment procedures mainly involve ultrasound evaluation of the deep veins in the supra-subclavicular and femoral regions and a seven-step procedure performed on both sides of the patient.[56,57]

Ultrasound-guided CICC and FICC placement is possible in infants of any gestational age and birth weight.[44,46–52] The only limitation is the internal diameter of the vein. International guidelines recommend selecting the appropriate vein by measuring the vein diameter before catheter placement, thereby reducing the risk of venous thrombosis.[5,53] The general recommendation is a catheter-to-vein diameter ratio of 1:3. This means that a vein with an internal diameter of at least 3mm is required for insertion of a 3Fr catheter.

In a recent study, the deep veins of 100 infants with an average gestational age of 32weeks and a birth weight of 1690g were evaluated by ultrasound. The brachiocephalic veins on both sides were found to have a diameter greater than 3mm and to be larger than the subclavian, internal jugular, and common femoral veins.[55] As a result, preference for the brachiocephalic vein has increased, as its lumen is not compressed due to its fixation to the surrounding tissue.

Ultrasound guidance enables percutaneous placement of relatively larger-diameter central venous catheters in extremely small infants. These large-caliber catheters can be used for inotropes, parenteral nutrition, transfusions, blood sampling, hemodynamic monitoring, and high-flow infusions. This approach may help reduce mortality and morbidity in critically ill premature infants.

Literature on the use of ultrasound for tip location in the neonatal population is limited.[26,58,59] The use of probes and acoustic windows similar to those used for peripherally inserted central catheters (PICC) is recommended.[46,52] Linear hockey stick and small sectoral probes are suitable. Acoustic windows may include the subcostal long-axis (bicaval) view, apical four-chamber view, and parasternal long-axis view (for the superior vena cava). The Neo-ECHOTIP recommendation includes ultrasound-guided venous puncture, ultrasound-based tip navigation, and ultrasound-based tip location.[26] The subcostal projection provides good visualization of the inferior vena cava and the terminal portion of the superior vena cava, while the apical four-chamber view offers a better view of the right atrium, and the high parasternal view provides good visualization of the superior vena cava and right atrial outflow.

In the tip navigation protocol for CICC, a linear probe is used to visualize the brachiocephalic veins bilaterally in the long axis.[39,55] Both the brachiocephalic vein and the SVC should be clearly visualized during the procedure. The needle should be visualized during venipuncture, and the guiding needle should be seen passing through the brachiocephalic vein and directed toward the SVC. The micro introducer should be visualized within the brachiocephalic vein. The catheter should then be visualized within both the brachiocephalic vein and the SVC.

For tip location determination, the use of a small sectorial probe is recommended. The tip location can be precisely visualized in three different windows: the subcostal longitudinal (bi-caval) view, the four-chamber apical view, and the long-axis view for the SVC. The procedure relies on tracking the catheter tip to the target area, the SVC/RA transition zone.[60,61] A small saline bolus (0.5–1ml) may be used to aid confirmation.[26,62]

The tip navigation protocol for FICC placement is performed in two steps. In the first step, the long and short axes of the femoral vein are visualized through the acoustic window using a linear probe. The femoral vein must be clearly visualized during needle puncture. The guidewire must then be visualized advancing in the long axis of the femoral vein. The micro introducer must be visualized within the femoral vein. In the final step, the catheter must be confirmed advancing in the femoral vein and the iliac vein. In the second step of navigation, the IVC is visualized using a small sectorial probe in the subcostal longitudinal view, allowing visualization of the catheter tip advancing within the IVC.

In the tip location protocol for FICC, the small sectorial probe is advanced to the target area, the IVC/RA junction, using the subcostal longitudinal view. A small amount (0.5–1ml) of saline bolus can be administered at this point to facilitate visualization.

Conclusions

The role of ultrasonography in the effective use of central venous access devices in neonatal intensive care units is becoming increasingly clear. The precision, speed, cost-effectiveness, and safety provided by ultrasound further enhance its appeal. Performing central venous catheter placement with direct visualization of the target vein and surrounding anatomical structures under real-time ultrasound guidance increases success rates and reduces complication rates.

In conclusion, ultrasound should be a primary consideration in central venous catheterization. Basic training in vascular ultrasonography and targeted echocardiography will likely increase both the frequency of use and the quality of the procedure.

Disclosures

Conflict of Interest: The authors declare that there is no conflict of interest.

Financial Disclosure: This study received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Use of AI for Writing Assistance: Not declared.

Authorship Contributions: Concept – A.U.Z., A.B.; Design – A.U.Z., A.B.; Supervision – A.B., H.S.U.; Fundings – A.U.Z., A.B., H.S.U.; Materials – A.U.Z., A.B., H.S.U.; Data collection &/or processing – A.U.Z., A.B.; Analysis and/or interpretation – A.U.Z., A.B.; Literature search – A.U.Z.; Writing – A.U.Z., A.B.; Critical review – A.U.Z., A.B., H.S.U.

Peer-review: Externally peer-reviewed.

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